

**AD-A276 697**



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**AUTOMATED DETECTION OF SHIP TRACKS IN  
MULTISPECTRAL SATELLITE DATA**

**PROGRESS REPORT #2**

**31 January 1994**



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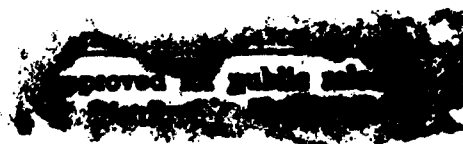
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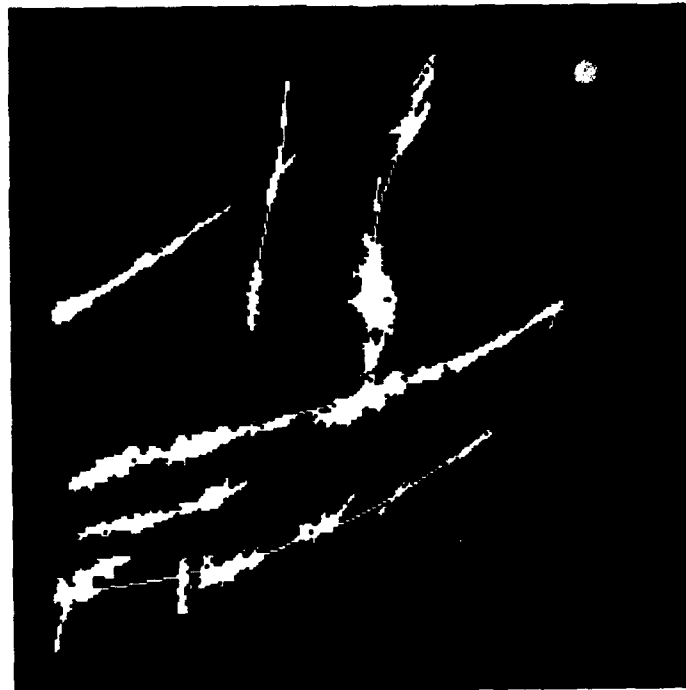
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# Automated Detection of Ship Tracks



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# **A Objectives**

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The objectives of this work are to develop robust ship track detection methods, demonstrate their utility using satellite imagery, and design the framework of an automated ship track detection system for operational use.

Our approach is to (1) use geographical and multispectral information to reduce the data stream greatly based on contexts for which ship tracks are physically allowed; (2) optimally enhance satellite images using multispectral signals; (3) apply state-of-the-art edge-detection, dilation and erosion operators in order to find and enhance candidate ship tracks with weak signatures; (4) determine features or parameters that best characterize the higher reflectivity and curvilinearity of ship tracks; (5) apply rule-based and cluster analysis techniques to reduce the data stream to a limited number of subscenes with potential tracks; (6) apply state-of-the-art neural net and statistical discriminant analysis methods as final detection filters; (7) assess detection success and error rates; (8) develop a prototype design of the automated system. The algorithms used here are ones that have exhibited success on this or similar problems.

Other related objectives of this effort are to (1) provide a critical review of successful elements of existing ship track detection schemes and refined multispectral enhancement methods that optimize track signatures; (2) establish the best set of features that objectively characterize ship tracks; (3) demonstrate the utility of advanced clustering, statistical and neural net classifiers and describe how they can be incorporated in an automated detection package; and (4) provide methods to assess detection error rates so that the performance of the system may be measured and clearly reported to policy makers. This work will also benefit other detection procedures, either by addressing unresolved issues, or by providing a framework to combine promising elements of those procedures in a single automated system.

# **B Progress**

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## **B.1 Introduction**

This report describes progress we have made in developing a system for automated detection of ship tracks. The algorithm analyzes multispectral digital image data acquired from the Advanced Very High Resolution Radiometers (AVHRR) aboard NOAA polar orbiting satellites. These images, both in the visible as well as near IR bands, contain characteristic signatures where ship effluents have enhanced the reflectivity of shallow marine layer clouds. The variability of meteorological conditions, combined with unknown ship track size, orientation and age provide a challenge for the design of a robust automated identification system.

Our approach for automated ship track identification proceeds in three distinct stages. The first stage consists of image enhancement of the AVHRR data. This preprocessing is detailed in Section B.2, which also includes examples of AVHRR images. Next is the cluster enumeration and feature calculation stage, as described in Section B.3, where potential ship tracks are isolated, processed and parameterized. The third stage then provides statistical classification analysis and probability assessment on the identified objects and their features, discriminating ship tracks from anomalous contrast variations. This statistical postprocessing stage is described in Section B.4. Here the probability assessment specifically addresses both success and error rates as applied to ship track detection using a database of known events. Progress to date has focused on the first two stages to quickly reduce the data stream significantly to a manageable number of potential ship track objects that can then be identified using state-of-the-art statistical classifiers.

On 21 January 1994, we briefed and provided a software demonstration to Prof. Phillip Durkee and Kurt Nielsen of the Naval Postgraduate School.

## B.2 AVHRR Image Enhancement

Our shiptrack detection algorithm uses as input a matched set of three AVHRR images: the visible channel 1 data ( $0.63 \mu\text{m} \pm 0.05 \mu\text{m}$ ), the near IR channel 3 data ( $3.74 \mu\text{m} \pm 0.19 \mu\text{m}$ ), and the channel 4 temperature data ( $10.8 \mu\text{m} \pm 0.5 \mu\text{m}$ ). These files have 8-bit pixel values and are typically 2048 pixels wide, although any pixel depth and size will be usable. For a typical scan of 4320 lines the three images require almost 30 Mbytes of storage. Clearly computational efficiency is an issue.

Figures 1, 2, and 3 depict an interesting North Pacific scan of 1024x1280 pixels taken from larger images. While the visible data shown in Figure 1 displays cloud structure, the channel 3 data clearly accentuates the apparent shiptrack detail. The channel 4 data is used as a temperature mask, with black (pixel value 0) calibrated to  $T=262\text{K}$  and white (pixel value 255) calibrated to  $T=313\text{K}$ . For example, Figure 4 illustrates a mask which excludes pixels with temperatures outside the interval 270K-290K. This clearly masks the land mass and is useful in the absence of geographical reference information on the satellite image location. In general, geographical information will be available and used. Further use of channel 4 data is described below.

### Image Thresholding

The temperature mask, as illustrated in Figure 4, can be applied to the channel 3 data to remove the land mass. The resultant pixmap is then enhanced by removing a smoothed background created from boxcar averaging of the image. Typically, a 31x31 window is used for this smoothing. At this point, the (8-bit deep) pixmap is converted to a (1-bit deep) bitmap by intensity thresholding. A cutoff, somewhere between the top 5% and the top 15% of the intensity histogram, is chosen to be imaged onto the bitmap. Selection of this parameter depends upon the apparent level of detail contained in the image. Feedback from the following cluster enumeration operation is used to adjust the intensity thresholding parameter if necessary. Figure 5 depicts a 9% threshold of the temperature-masked channel 3 sample data.

**Figure 1. AVHRR channel 1 8-bit 1024x1280 image.**



**Figure 2. AVHRR channel 3 8-bit 1024x1280 image.**





**Figure 3. AVHRR channel 4 8-bit 1024x1280 image.**



**Figure 4. Temperature mask of 1024x1280 channel 4 image.**



**Figure 5. Temperature masked and 9% thresholded bitmap image.**



### **Angular Convolution**

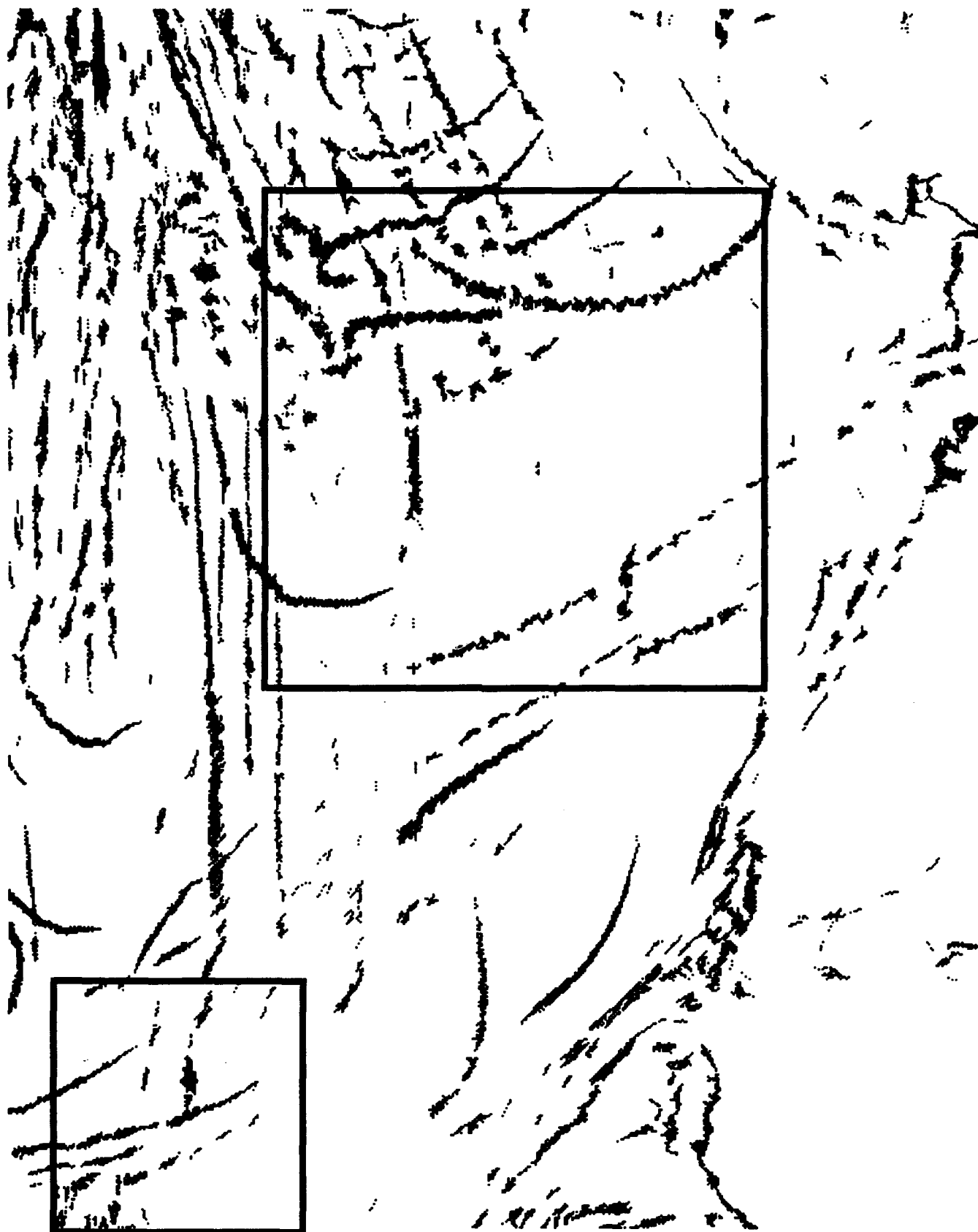
The next step of image preprocessing is a convolution of the data with a set of linear kernels. Note the significant amount of random noise present in the thresholded image of Figure 5. Potentially interesting ship tracks have linear components on a scale of, say, 10 km or more. The purpose of the convolution is to filter out active pixel regions which have no linear component on a scale of at least 10 pixels, thereby improving the ship track signal-to-noise ratio and enhancing the remaining curvilinear objects present in the bitmap.

To accomplish this convolution, a set of  $N \times N$  kernels is constructed representing single-pixel-width straight lines passing through the origin at every discrete angle. Using  $N=11$ , there are 49 such unique kernels in the set. Successively applying each kernel, we first *erode* the image and then *dilate* the result. These operations represent line thinning and thickening, respectively, with respect to the structure of the kernel. The kernels are applied on a sliding window across the full image, and the *union* of this dilate/erode operation comprises the convolved image. Consequently any orientation angle feature will survive as long as a linear component greater than 10 pixels exists.

Figure 6 depicts the convolved image for the 1024x1280 subscene in our example. In comparison with Figure 5, the reduced noise content is obvious while the ship track structures appear intact. This convolution has the added advantage of being computationally efficient.

Note that some of the coastline structure has survived along the right hand portion of the image. In addition, the far upper left region of the image appears to be obscured by cloud structure. The feature analysis stage, as described in the next section, will be responsible for discriminating this remaining coastline and cloud structure from the desired ship tracks. To do this, channel 1 visible data and channel 4 temperature data will be analyzed.

**Figure 6. Angular convolution of 1024x1280 bitmap image.**



## **B.3      *Feature Analysis***

The previous processing steps have converted the original channel 3 8-bit pixmap into a binary image or bitmap, removed geographical regions for which ship tracks are infeasible, and filtered out elements of the bitmap that do not possess linear structure consistent with that of ship tracks. This results in a bitmap which retains the ship tracks while greatly enhancing the signal-to-noise and simplifying the remaining structure to be further analyzed.

The next processing task is region enumeration. Rather than compute properties of individual pixels, groups of connected pixels are formed which break the entire image into disjoint regions. This reduces the number of objects for which detailed properties are computed by several orders of magnitude. Neighboring regions of every object can be examined to determine if they belong together or require further decomposition. This analysis is motivated by the fact that low thresholds may yield combined regions in the bitmap that are physically distinct in the original image or multiple ship tracks may intersect, resulting in complicated bitmap objects that require decomposition before attempting to classify. Alternatively, if the threshold is set too high or the cloud field is broken, a ship track may appear in the bitmap as a set of piecewise collinear regions which need to be joined together. This analysis, in fact, provides a feedback mechanism with which to adjust the intensity threshold.

### **Region Enumeration**

Region enumeration is designed to identify all disjoint regions that comprise the entire image. Neighboring pixels (i.e., lying in any one of eight adjacent pixels), both with value 1 in the bitmap, are considered members of the same region. Any two distinct regions may not have any such neighbors.

The number of enumerated disjoint regions ranges from one to one-fourth of the number of pixels in the image. The channel 3 intensity threshold set above controls the number of regions and their average size. The enumerated regions must be large enough to contain linear components of some useful size, perhaps 10 km, yet small

enough so that multiple ship tracks are disconnected. In this regard, it is more efficient to limit region sizes to smaller levels, since it is easier to combine multiple disjoint regions of ship tracks that display a piecewise linear character.

Once regions are initially enumerated, preliminary *features* are computed for each. Computed are the region's area, center of gravity, length, width, orientation angle, aspect ratio, two nearest neighbors and their relative distances. The number of regions and their features are re-computed after the chunk decomposition and linear recombination stages.

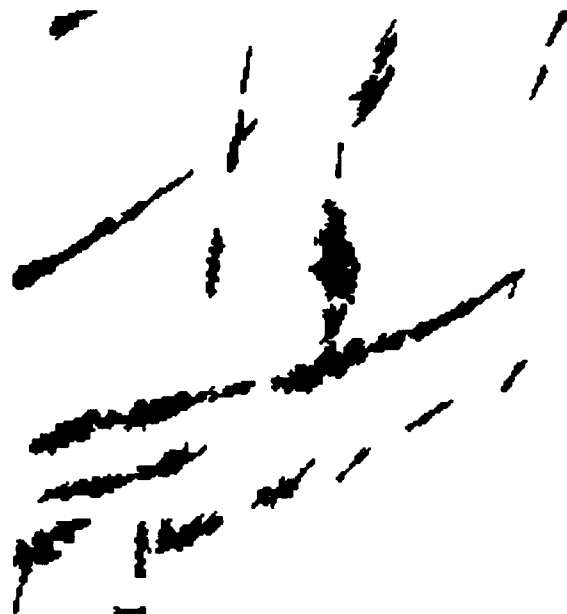
Figure 7 expands the 256x256 subsection identified in the lower left corner of Figure 6. This particular subsection has been thresholded at 7% and exactly 22 disjoint regions are present. The areas of the initially enumerated regions range from 21 to 626 pixels, with lengths ranging from 15 to 109 pixels. Many of these disjoint regions will be combined in the following analysis. Figure 8 shows the six ship tracks which ultimately survive.

### **Feature Calculation and Cluster Categoration**

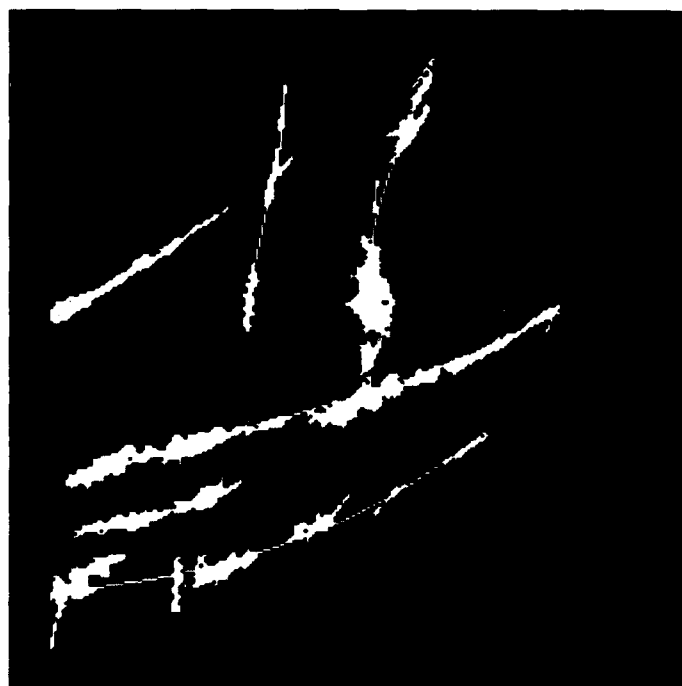
The aspect ratio of the disjoint regions (which we also refer to as objects) is a particularly useful feature for discriminating components of ship tracks from other objects. To estimate the aspect ratio of a region, we use the 2D moment of inertia taken about its center of gravity. The aspect ratio is given by the square root of the ratio of minimum-to-maximum inertia eigenvalues. In addition, the orientation angle of the object is estimated from the 2D eigenvector rotation angle.

Regions are categorized into clusters. Large objects having sizeable aspect ratios, perhaps  $> 0.35$  with area  $> 5000$ , are identified as *chunks*. Those objects with sizeable aspect ratios which fail the large area test are identified as *blobs*. Objects with linear-like aspect ratios having short lengths, perhaps  $< 50$  pixels, are called *stubs*. The remaining objects constitute potentially interesting curvilinear regions.

**Figure 7. 256x256 subsection of image thresholded at 7%.**



**Figure 8. Ship tracks identified from 256x256 subsection.**





Physically, coastlines exhibit a fractal-like structure and are thus generally enumerated into multiple short regions or stubs. If these regions are allowed to become interconnected, perhaps by inefficient thresholding of the image, they can appear to be jagged piecewise-linear segments. This is exhibited somewhat in the lower right portion of Figure 5. In severely under-thresholded cases, coastline will appear to be one or more chunks.

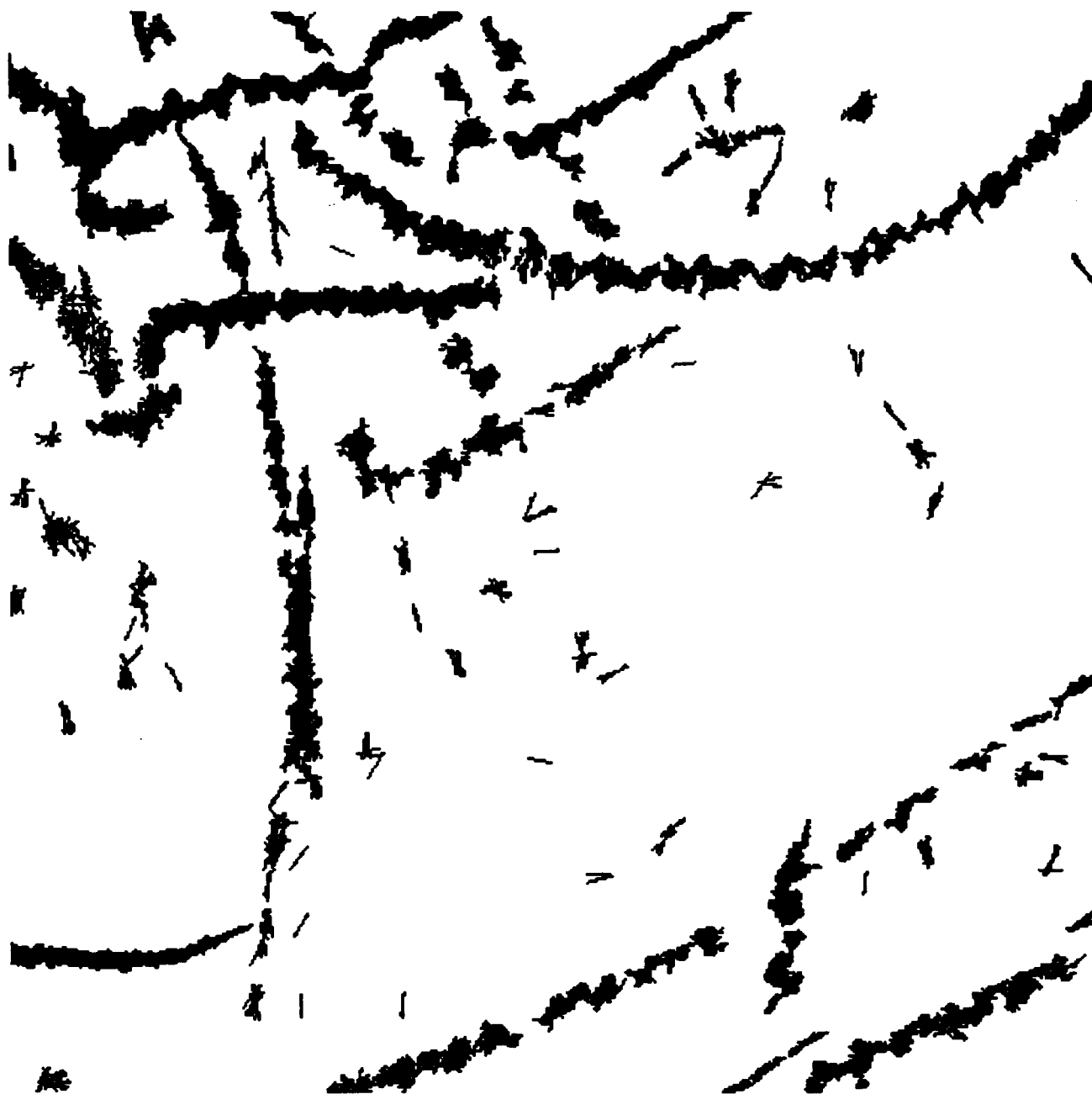
Cloud cover can break ship tracks into multiple disjoint objects as well. The image processing stage must be able to reconstruct piecewise-linear segments from so many disjoint components. This we will call collinear recombination. Additionally, ship tracks may spread and/or weaken significantly with age, hence the aspect ratios of the individual disjoint component regions may appear as blobs.

### **Chunk Decombobulation**

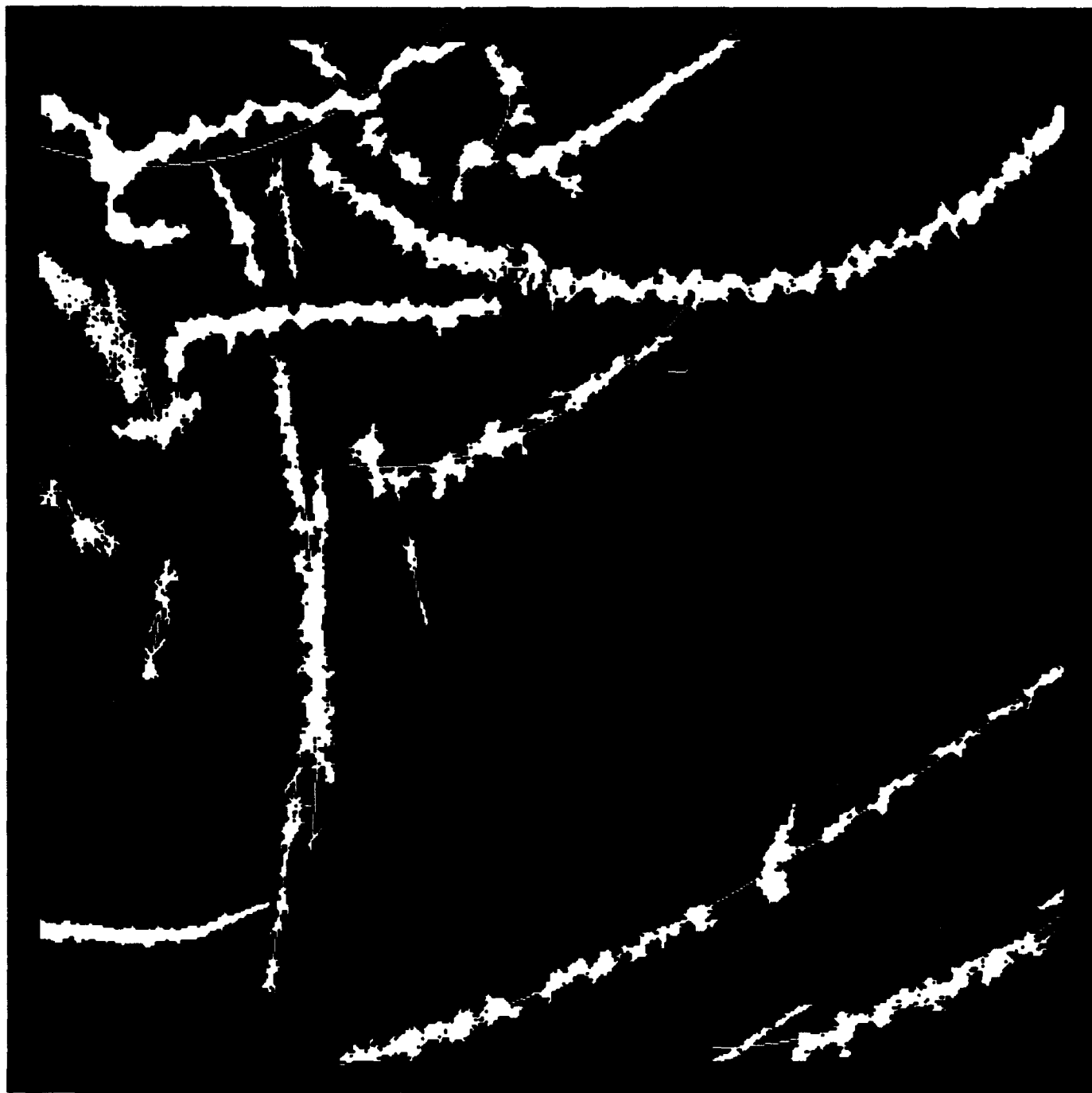
Large chunks, whether from semifragmented coastline or from connected linear elements of multiple ship tracks, must be either eliminated or decomposed into more fundamental objects. If too many chunks are present in the thresholded bitmap, the image should be re-thresholded at a lower intensity cutoff. Otherwise, chunks can be decomposed into smaller objects. This is done by computing the mean number of nearest neighbors for the region and choosing a zeroing level less than this mean. Pixels which have fewer neighbors than the zeroing level are zeroed, and the chunk is re-enumerated. The process is repeated (rarely necessary) until the decomposed objects contain no chunks.

Figure 9 represents an 11% thresholded subsection of Figure 2. This subsection is a 512x512 cut taken from the top central portion of the larger image, as indicated by the larger box displayed within Figure 6, specifically containing the large (about 400 pixels in length) parabolic ship track near the top of the cut. Here the increased thresholding level has created a chunk immediately to the left of the noted parabolic track. The chunk appears as an "H" on its side, has an area of 5581 pixels, and the mean number of nearest neighbors 6.26. This chunk is decombobulated by zeroing all pixels with less than 6 nearest neighbors. The net effect is to break the "H" into

**Figure 9. 11% thresholded 512x512 subsection.**



**Figure 10. Potential ship tracks identified from 512x512 subsection.**



**Table 1: Features of 68 Objects Identified from 512x512 Subsection.**

Region Size Analysis for 68 features:

			20	50	100	200	500	1000	2000	5000									
			9	15	15	4	12	4	8	1	0								
16 Blobs																			
...	r#	58 Area	453	<>	<>	<Y	193	Asp	0.386	Ang	25	Len	48	nn#	57	Dist	15		
...	r#	11 Area	302	<>	<>	<Y	442	Asp	0.399	Ang	76	Len	41	nn#	17	Dist	11		
...	r#	63 Area	264	<>	<>	<Y	171	Asp	0.416	Ang	-47	Len	38	nn#	54	Dist	14		
...	r#	93 Area	201	<>	<>	<Y	24	Asp	0.852	Ang	-64	Len	28	nn#	97	Dist	39		
...	r#	76 Area	185	<>	<>	<Y	106	Asp	0.470	Ang	-40	Len	27	nn#	73	Dist	22		
...	r#	89 Area	145	<>	<>	<Y	48	Asp	0.455	Ang	-56	Len	24	nn#	79	Dist	10		
...	r#	87 Area	116	<>	<>	<Y	57	Asp	0.571	Ang	43	Len	20	nn#	78	Dist	26		
...	r#	2 Area	93	<>	<>	<Y	491	Asp	0.666	Ang	4	Len	18	nn#	13	Dist	53		
...	r#	8 Area	73	<>	<>	<Y	456	Asp	0.418	Ang	80	Len	19	nn#	18	Dist	9		
...	r#	40 Area	69	<>	<>	<Y	299	Asp	0.368	Ang	89	Len	22	nn#	38	Dist	9		
...	r#	28 Area	65	<>	<>	<Y	354	Asp	0.779	Ang	15	Len	16	nn#	32	Dist	7		
...	r#	45 Area	62	<>	<>	<Y	271	Asp	0.639	Ang	-15	Len	16	nn#	48	Dist	23		
...	r#	44 Area	61	<>	<>	<Y	276	Asp	0.485	Ang	83	Len	15	nn#	47	Dist	36		
...	r#	29 Area	60	<>	<>	<Y	344	Asp	0.546	Ang	-75	Len	21	nn#	27	Dist	33		
...	r#	23 Area	57	<>	<>	<Y	389	Asp	0.394	Ang	-80	Len	16	nn#	26	Dist	15		
...	r#	39 Area	51	<>	<>	<Y	304	Asp	0.352	Ang	-69	Len	16	nn#	46	Dist	15		
31 Short features																			
...	r#	17 Area	412	<>	<>	<Y	403	Asp	0.326	Ang	76	Len	48	nn#	11	Dist	11		
...	r#	85 Area	218	<>	<>	<Y	70	Asp	0.256	Ang	10	Len	44	nn#	82	Dist	3		
...	r#	77 Area	100	<>	<>	<Y	91	Asp	0.137	Ang	63	Len	41	nn#	85	Dist	4		
...	r#	56 Area	98	<>	<>	<Y	205	Asp	0.184	Ang	-55	Len	40	nn#	50	Dist	8		
...	r#	90 Area	67	<>	<>	<Y	48	Asp	0.296	Ang	86	Len	20	nn#	88	Dist	10		
...	r#	82 Area	54	<>	<>	<Y	81	Asp	0.242	Ang	40	Len	18	nn#	85	Dist	3		
...	r#	33 Area	54	<>	<>	<Y	330	Asp	0.304	Ang	-77	Len	18	nn#	42	Dist	27		
...	r#	25 Area	50	<>	<>	<Y	382	Asp	0.218	Ang	52	Len	23	nn#	20	Dist	21		
...	r#	57 Area	49	<>	<>	<Y	203	Asp	0.766	Ang	34	Len	15	nn#	58	Dist	15		
...	r#	50 Area	46	<>	<>	<Y	231	Asp	0.250	Ang	69	Len	17	nn#	56	Dist	8		
...	r#	88 Area	45	<>	<>	<Y	54	Asp	0.195	Ang	-67	Len	18	nn#	90	Dist	10		
...	r#	49 Area	44	<>	<>	<Y	236	Asp	0.727	Ang	11	Len	20	nn#	48	Dist	17		
...	r#	21 Area	40	<>	<>	<Y	394	Asp	0.391	Ang	66	Len	19	nn#	5	Dist	28		
...	r#	55 Area	36	<>	<>	<Y	224	Asp	0.476	Ang	32	Len	18	nn#	66	Dist	57		
...	r#	66 Area	34	<>	<>	<Y	168	Asp	0.432	Ang	-78	Len	15	nn#	56	Dist	16		
...	r#	71 Area	33	<>	<>	<Y	127	Asp	0.137	Ang	-54	Len	19	nn#	72	Dist	77		
...	r#	78 Area	33	<>	<>	<Y	94	Asp	0.246	Ang	90	Len	17	nn#	87	Dist	26		
...	r#	32 Area	32	<>	<>	<Y	347	Asp	0.244	Ang	-10	Len	15	nn#	28	Dist	7		
...	r#	64 Area	30	<>	<>	<Y	174	Asp	0.699	Ang	57	Len	15	nn#	57	Dist	28		
...	r#	83 Area	28	<>	<>	<Y	79	Asp	0.208	Ang	-85	Len	14	nn#	99	Dist	27		
...	r#	38 Area	27	<>	<>	<Y	309	Asp	0.172	Ang	27	Len	17	nn#	40	Dist	9		
...	r#	20 Area	26	<>	<>	<Y	400	Asp	0.363	Ang	8	Len	14	nn#	25	Dist	21		
...	r#	36 Area	20	<>	<>	<Y	311	Asp	0.127	Ang	-63	Len	16	nn#	42	Dist	16		
...	r#	10 Area	15	<>	<>	<Y	458	Asp	0.109	Ang	85	Len	15	nn#	9	Dist	44		
...	r#	48 Area	13	<>	<>	<Y	254	Asp	0.092	Ang	4	Len	14	nn#	49	Dist	17		
...	r#	15 Area	13	<>	<>	<Y	422	Asp	0.073	Ang	58	Len	16	nn#	18	Dist	16		
...	r#	22 Area	13	<>	<>	<Y	392	Asp	0.068	Ang	52	Len	15	nn#	18	Dist	18		
...	r#	19 Area	13	<>	<>	<Y	403	Asp	0.108	Ang	83	Len	13	nn#	26	Dist	13		
...	r#	9 Area	11	<>	<>	<Y	458	Asp	0.000	Ang	0	Len	13	nn#	8	Dist	22		
...	r#	31 Area	11	<>	<>	<Y	348	Asp	0.080	Ang	-12	Len	13	nn#	38	Dist	42		
...	r#	75 Area	11	<>	<>	<Y	120	Asp	0.071	Ang	-23	Len	14	nn#	74	Dist	24		
21 Possibly interesting features																			
...	r#	99 Area	2387	<>	<>	<Y	62	Asp	0.318	Ang	18	Len	233	nn#	62	Dist	3		
...	r#	27 Area	1805	<>	<>	<Y	272	Asp	0.086	Ang	-85	Len	217	nn#	97	Dist	33		
...	r#	95 Area	1580	<>	<>	<Y	146	Asp	0.110	Ang	6	Len	193	nn#	73	Dist	8		
...	r#	5 Area	1360	<>	<>	<Y	466	Asp	0.136	Ang	23	Len	182	nn#	11	Dist	28		
...	r#	73 Area	1335	<>	<>	<Y	105	Asp	0.166	Ang	-26	Len	144	nn#	95	Dist	8		
...	r#	3 Area	1332	<>	<>	<Y	465	Asp	0.064	Ang	23	Len	218	nn#	17	Dist	20		
...	r#	69 Area	1273	<>	<>	<Y	130	Asp	0.108	Ang	1	Len	151	nn#	72	Dist	3		
...	r#	54 Area	1238	<>	<>	<Y	200	Asp	0.194	Ang	23	Len	185	nn#	46	Dist	31		
...	r#	72 Area	1131	<>	<>	<Y	91	Asp	0.117	Ang	34	Len	158	nn#	69	Dist	3		
...	r#	62 Area	980	<>	<>	<Y	148	Asp	0.264	Ang	-54	Len	89	nn#	99	Dist	3		
...	r#	80 Area	960	<>	<>	<Y	54	Asp	0.158	Ang	33	Len	137	nn#	73	Dist	25		
...	r#	13 Area	727	<>	<>	<Y	435	Asp	0.120	Ang	4	Len	117	nn#	18	Dist	9		
...	r#	26 Area	519	<>	<>	<Y	354	Asp	0.049	Ang	36	Len	175	nn#	32	Dist	18		
...	r#	79 Area	496	<>	<>	<Y	53	Asp	0.322	Ang	68	Len	90	nn#	99	Dist	10		
...	r#	84 Area	467	<>	<>	<Y	52	Asp	0.121	Ang	-50	Len	118	nn#	73	Dist	35		
...	r#	97 Area	355	<>	<>	<Y	104	Asp	0.175	Ang	-69	Len	62	nn#	74	Dist	16		
...	r#	18 Area	296	<>	<>	<Y	396	Asp	0.100	Ang	82	Len	89	nn#	27	Dist	11		
...	r#	47 Area	280	<>	<>	<Y	243	Asp	0.321	Ang	-44	Len	51	nn#	42	Dist	21		
...	r#	42 Area	212	<>	<>	<Y	287	Asp	0.130	Ang	80	Len	75	nn#	36	Dist	24		
...	r#	74 Area	184	<>	<>	<Y	98	Asp	0.150	Ang	-78	Len	62	nn#	73	Dist	14		
...	r#	46 Area	80	<>	<>	<Y	264	Asp	0.095	Ang	-78	Len	53	nn#	54	Dist	17		

three disjoint segments. Figure 10 illustrates the resulting ship tracks identified from within this subsection.

### **Collinear Recombination**

Once the chunks are removed, we are left with blobs, stubs, and potentially interesting ship track components. The purpose of the collinear recombination is to assemble piecewise linear tracks from the remaining enumerated regions. Each region is tested with its immediate neighbors for collinearity. If two regions are neither blobs nor stubs, their orientation angle's difference tangent must fall below a specified limit, which is typically 0.5. Additionally, the difference in the tangent of the mean orientation angle and a line connecting the two center of gravities must pass a similar test. Table 1 identifies the 68 objects associated with Figure 10, of which 16 are blobs and 31 are stubs.

Remaining potentially interesting objects are then fit with polynomials, typically either quadratics or cubics. These curves are extrapolated on each end some specified distance, typically 30 to 50 pixels, and more collinearity tests are applied to the intersecting regions. Collinear regions are combined if they pass the tests. In the case illustrated by Figure 10 and summarized in Table 1, two blobs, two stubs, and one possibly interesting object represent the curve fit acquisitions. This leaves 20 possibly interesting objects, and their fits, which are those plotted in Figure 10. The curve fits are parameterized as either  $i(j)$  or  $j(i)$ , depending upon the curve's orientation angle, where  $i$  is the horizontal vector and  $j$  is the vertical. In the coordinate system of the figures,  $i=j=0$  represents the top left hand corner of the plot. Table 2 summarizes the quadratic fits applied in this case.

### **Temperature Exclusion**

Channel 4 data is now referenced for each prospective ship track. Here we use the temperature calibration of 0.2K/pixel-value with a temperature band of 262K to 313K, for pixel values ranging from 255 to 0, respectively. The mean and rms temperatures along each curve are computed, as well as along parallel curves spaced some specified distance (typically 10 pixels) along either side. The curve's mean

temperature must fall within a specified interval appropriate for the geographical area. Additionally, the lateral temperature gradient using both excursion paths is tested to indicate coastline or cloudcover bordering the object. Prospective ship tracks may be rejected at this stage; if not, the information will be available to the statistical classifier for further processing.

### Visible Exclusion

Channel 1 visible data is also referenced for each prospective ship track. The mean and rms values are computed along each curve, as are the lateral excursion mean and rms values. As with the temperature data, the lateral gradient is examined to ensure the curve's central mean value is a local maximum. Prospective tracks may either be rejected or retained for the statistical classification stage.

**Table 2: Quadratic Fits for Interesting Objects of 512x512 Subsection.**

```

... 20 features coded into 13240 bytes.
... 14 blobs have NOT been plotted.
... 29 short regions have NOT been plotted.
... r# 1 j= 430 497 i(j)= 1.03E+03-2.93E+00*j*(1-7.79E-04*j)
... r# 1 Area 467 <X> 169 <Y> 52 Asp 0.121 Ang -50 Len 117.6 Width 4.0
... r# 2 j= 422 495 i(j)= -2.92E+03+1.34E+01*j*(1-1.06E-03*j)
... r# 2 Area 496 <X> 228 <Y> 53 Asp 0.322 Ang 68 Len 89.8 Width 5.5
... r# 3 i= 236 345 j(i)= 5.35E+02-1.16E+00*i*(1-2.68E-03*i)
... r# 3 Area 960 <X> 281 <Y> 54 Asp 0.158 Ang 33 Len 136.8 Width 7.0
... r# 4 i= 17 216 j(i)= 4.54E+02-4.60E-01*i*(1-7.36E-03*i)
... r# 4 Area 2387 <X> 90 <Y> 62 Asp 0.318 Ang 18 Len 233.1 Width 10.2
... r# 5 i= 386 497 j(i)= 8.97E+02-2.84E+00*i*(1-1.39E-03*i)
... r# 5 Area 1131 <X> 446 <Y> 91 Asp 0.117 Ang 34 Len 158.1 Width 7.2
... r# 6 j= 386 442 i(j)= 2.23E+01+7.35E-01*j*(1-1.55E-03*j)
... r# 6 Area 184 <X> 130 <Y> 98 Asp 0.150 Ang -78 Len 62.3 Width 3.0
... r# 7 j= 382 438 i(j)= -5.64E+02+3.68E+00*j*(1-1.35E-03*j)
... r# 7 Area 355 <X> 109 <Y> 104 Asp 0.175 Ang -69 Len 62.1 Width 5.7
... r# 8 i= 142 254 j(i)= 6.78E+02-2.31E+00*i*(1-2.01E-03*i)
... r# 8 Area 1335 <X> 198 <Y> 105 Asp 0.166 Ang -26 Len 144.2 Width 9.3
... r# 9 i= 254 384 j(i)= 4.68E+02-5.58E-01*i*(1-1.61E-03*i)
... r# 9 Area 1273 <X> 315 <Y> 130 Asp 0.108 Ang 1 Len 151.2 Width 8.4
... r# 10 i= 74 233 j(i)= 3.21E+02+5.40E-01*i*(1-2.67E-03*i)
... r# 10 Area 1580 <X> 144 <Y> 146 Asp 0.110 Ang 6 Len 193.4 Width 8.2
... r# 11 j= 305 398 i(j)= -4.05E+02+3.27E+00*j*(1-1.71E-03*j)
... r# 11 Area 1433 <X> 51 <Y> 162 Asp 0.250 Ang -55 Len 129.4 Width 11.1
... r# 12 i= 161 320 j(i)= 4.19E+02-1.37E+00*i*(1-2.79E-03*i)
... r# 12 Area 1238 <X> 224 <Y> 200 Asp 0.194 Ang 23 Len 185.1 Width 6.7
... r# 13 i= 16 53 j(i)= 3.17E+02-2.08E+00*i*(1-9.13E-03*i)
... r# 13 Area 280 <X> 35 <Y> 243 Asp 0.321 Ang -44 Len 50.9 Width 5.5
... r# 14 j= 222 264 i(j)= 4.48E+02-1.90E+00*j*(1-1.84E-03*j)
... r# 14 Area 80 <X> 191 <Y> 264 Asp 0.095 Ang -78 Len 52.8 Width 1.5
... r# 15 j= 115 349 i(j)= 1.21E+02+2.72E-01*j*(1-2.71E-03*j)
... r# 15 Area 1818 <X> 141 <Y> 273 Asp 0.086 Ang -85 Len 220.2 Width 8.3
... r# 16 j= 196 253 i(j)= -4.66E+00+5.14E-01*j*(1-1.51E-03*j)
... r# 16 Area 212 <X> 70 <Y> 287 Asp 0.130 Ang 80 Len 74.6 Width 2.8
... r# 17 j= 48 154 i(j)= 1.15E+02+1.73E-01*j*(1-1.13E-03*j)
... r# 17 Area 369 <X> 129 <Y> 408 Asp 0.068 Ang 82 Len 125.6 Width 2.9
... r# 18 i= 157 497 j(i)= -1.33E+01+5.07E-02*i*(1+1.54E-02*i)
... r# 18 Area 2263 <X> 309 <Y> 428 Asp 0.069 Ang 29 Len 422.2 Width 5.4
... r# 19 i= 16 123 j(i)= 8.31E+01-3.44E-01*i*(1-9.19E-03*i)
... r# 19 Area 727 <X> 60 <Y> 435 Asp 0.120 Ang 4 Len 116.6 Width 6.2
... r# 20 i= 332 497 j(i)= 2.60E+02-1.46E+00*i*(1-1.53E-03*i)
... r# 20 Area 1360 <X> 421 <Y> 466 Asp 0.136 Ang 23 Len 181.8 Width 7.5
... # features selected: 20

```

## B.4 Statistical Classification

Having greatly reduced the data stream to a manageable number of potentially interesting objects and computed their characteristic features, advanced statistical classification methods can be employed to further distinguish ship tracks from other nondescript objects. Table 3 lists 31 features which were computed for each object. These may be combined with other contextual features: ocean basin, relative wind velocity information, temperature, humidity, cloud type and temperature, meteorological and boundary layer background conditions, etc.

We are in the process of establishing reference data sets with a high degree of ground-truth to train our statistical classifiers. We will describe these methods and their applications in the third progress report.

Table 3: Computed Features for Potentially Interesting Objects.

1	FLAG	<0 if object failed a previous test
2	R#	Region number from 2 through N
3	AREA	Area of region in pixels
4	<C>	CG of region
5	<L>	
6	<I>	Integrated path length
7	<W>	Computed width of region
8	asp	Aspect ratio
9	ang	Orientation angle
10	rms	Quadratic (or higher) fit's RMS for this region
11	delta	Maximum distance any part of the fit is away from region
12	<T>	Mean temp (& rms) along fit of region
13	T+rms	
14	<T+>	Excursion temp (& rms) on +10 pixel parallel fit path
15	T+rms	
16	<T->	Excursion temp (& rms) on -10 pixel parallel fit path
17	T-rms	
18	<V>	Same as temp, except visible (.63micron) image
19	v+rms	
20	<V+>	
21	v+rms	
22	<V->	
23	v-rms	
24	fitflag	1 => i(j), 2 => j(i) for the fit's parameterization
25	imin (jmin)	Extrema of fit
26	imax (jmax)	
27	c0	
28	c1	Assuming a quadratic fit, these are the 3 parameters
29	c2	
30	nn	Nearest neighbor to this region
31	nn-dist	Distance of nearest neighbor

### **C. Difficulties Encountered**

None

### **D. Plans for the Next Reporting Period**

During the next reporting period, we will apply statistical classification and outlier detection methods to the feature data of objects extracted from the preliminary stages of analysis. We will demonstrate that these methods are useful and efficient for identifying ship tracks. This effort requires that we first establish training sets based on images for which ship tracks have been identified to a high degree of confidence. During the last period of this Phase I effort, we will also examine issues associated with developing a prototype system and fusing data from multiple external sources such as JMIE, and compiling .

### **E. Property**

None

### **F. Personnel Changes and Important Administrative Changes**

None

### **G. Travel**

On 3 December 1993, Dr. Mark Fisk met with Dr. Robert Bluth of ONR to discuss progress on this project. On 23, 24 December 1993, Dr. Fisk met with Prof. Henry Gray (Consultant to MRC) to discuss the status and future direction of this work.

### **H. Funding**

Of the total contract funds of \$59,972 authorized for 6 months, approximately \$49,787 have been expended for 4 months, and 83% of the work has been completed.



MATERIAL INSPECTION AND RECEIVING REPORT						Form Approved OMB No 0704-0248						
1 PROC INSTRUMENT IDEN (CONTRACT) <b>N00014-93-C-0197</b>			ORDER NO		6 INVOICE		7 PAGE <b>1</b>		OF <b>1</b>		8 ACCEPTANCE POINT <b>D</b>	
2 SHIPMENT NO <b>MRC002</b>		9 DATE SHIPPED <b>94FEB28</b>		4 B/L		5 DISCOUNT TERMS <b>NET 30 DAYS</b>						
9 PRIME CONTRACTOR <b>Mission Research Corporation 735 State Street; P.O. Drawer 719 Santa Barbara, CA 93102-0719</b>				CODE <b>1G992</b>		10 ADMINISTERED BY <b>DCASMA, Van Nuys 6230 Van Nuys Blvd. Van Nuys, CA 91408</b>				CODE <b>S0512A</b>		
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